Design and Implementation of A Lumped-Element Multipole HTS Filter at 15 MHz

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Abstract — **We have designed a three-pole bandpass filter operating at 15 MHz. The parameters of the filter include high Q, narrow band, low insertion loss and a return loss of 20 dB. The filter was fabricated from double-sided YBCO thin film on a two inch LAO substrate. Our design utilizes individual HTS lumped elements (interdigital capacitors and meander line inductors) to of the poles of the filter. The design and modeling of the filter are discussed in detail. Experimental results from the S-parameter measurements will be presented. Good agreement has been found between the simulation results and experimental data.**

I. INTRODUCTION

High temperature superconductors have been used for microwave applications since their discovery in 1986. Due to low surface resistance of the superconductors, the insertion loss of HTS filters can be greatly reduced as well as reducing its bandwidth (increasing the Q-value). Superconducting planar filters with low insertion loss and high out-of-band rejection have been reported in resent years [1]-[6]. However, most of them were operating at gigahertz (GHz) or higher frequencies. As the frequency decreases, it is challenging to design HTS filters within limited area.

In this paper we will report, for the first time, the design, fabrication and measurement of a three-pole HTS(double-sided YBCO thin film) microstrip bandpass filter operating at 15 MHz.

II. THREE-POLE HTS BANDPASS FILTER

1. Design

The bandpass filter is transformed from a three-pole Chebyshev lowpass prototype with specification shown in Table I. The circuit was simulated with HP EESof IV, a microwave communication circuit simulation suite[12]. The simulated filter response is shown in Fig. 1.

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TABLE I
FILTER DESIGN CHARACTERISTICS

Central Frequency f_0	15 MHz
Band width (BW)	15 kHz
Insertion Loss (S12)	< 1 dB
Return Loss (S11)	> 20 dB
Stop Band at 4 times BW	< -40 dB

2. Implementation of the Filter

Since the filter was designed on a two inch wafer, lumped elements were chosen to meet this requirement for their compact structure. The filter was implemented based on two microstrip structures - interdigital capacitor and meander line inductor (Fig. 2).

The interdigital capacitor is a well defined lumped capacitor structure. It has been widely used for microwave applications[7].

The advantage of the meander line is its coplanar structure. The normal spiral inductor structure requires an air bridge that causes too much additional loss. Though the meander line structure is not as efficient as the spiral one in terms of inductance per unit area, its coplanar structure avoids the loss due to wire bonding.

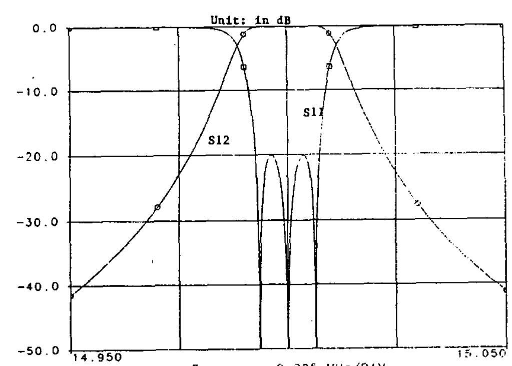

Fig. 1. Circuit simulation result with HP EESof.

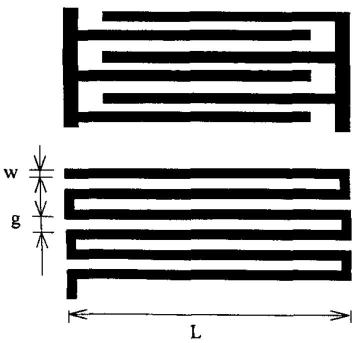

Fig. 2 Interdigital capacitor (top) and meander line inductor structure (bottom).

A model for the meander line structure has been built to implement the filter. The inductance is calculated with the following formula:

$$L = Ls + M \qquad (\mu H) \tag{1}$$

where

$$Ls = 2\times 10^{-4}\, n \times (l+g) \times \log\left(\frac{l+g}{w+t} + 1.193 + 0.2235\frac{w+t}{l+g}\right) \tag{2}$$

$$M = 2\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left[(-1)^{i-j}\frac{\mu}{4\pi}\times 10^{3}\times l \times \left(2\sqrt{a^2} - 2\sqrt{1+a^2} + \log\frac{\sqrt{1+a^2}+1}{\sqrt{1+a^2}-1}\right)\right] \tag{3}$$

$$a = (i-j)\frac{g}{l} \tag{4}$$

Where t is the thickness of the HTS film, w, g and l are shown in Fig. 2 with their dimensions in μm. Ls is the self inductance of all lines (total number of n) and M is the mutual inductance between lines with both units in μH[11].

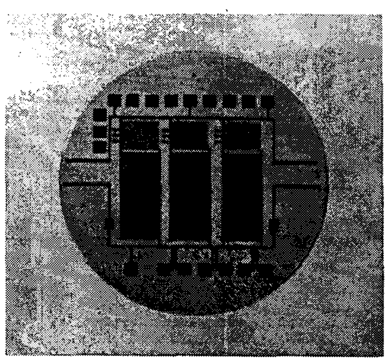

Fig. 3. Photograph of a three-pole filter.

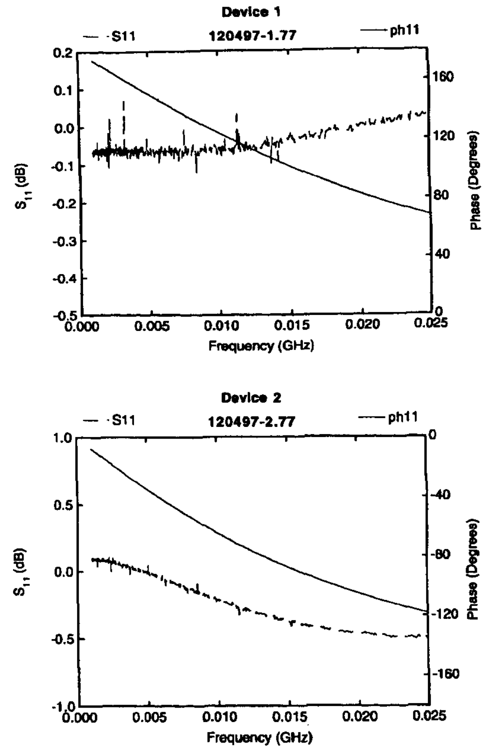

Fig. 4. Testing result of inductor (top) and capacitor (bottom) made from YBCO film.

A few lumped elements were tested at 77 K. The results agree well with our simulation. As shown in Fig. 4, the phases (solid lines) of the inductor and capacitor are 90 degrees and -90 degrees at 15 MHz, respectively.

3. *Performance of Three-pole HTS Filter*

Several filters were fabricated on two-inch wafers (200 nm YBCO on 0.5 mm LAO substrate) (Fig. 3). Contact pads were made by lift-off with 150 nm gold on top of 50 nm silver.

All filters were characterized at a standard microwave testing bed. The temperature in the system could be adjusted from room temperature down to 10 K. An Indium/gold plate was put underneath the HTS grounding plane to get good thermal and electrical conduction. The experiment has been carried out at different temperature (13 K, 30 K and 50 K). The filter showed a stable power handling ability with input power varying from -30 dBm up to 0 dBm.

Figure 5 is the S-parameter response of a filter at 13 K. It shows a filter response with three poles; these three peaks also demonstrate that each resonator has a very high Q (about 1000). Obviously, there is mismatch between these poles which makes the insertion loss low and the bandwidth wide.

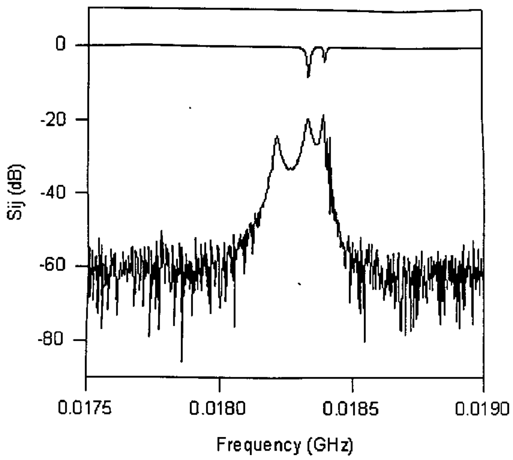

Fig. 5. Response of a three-pole bandpass filter with input power of -20 dBm at 13 K.

4. Analysis and Discussion

Analysis shows that the mismatch is mainly due to the small coupling capacitors between resonators. The value of the coupling capacitors are three orders smaller than that of the resonance capacitors (about 0.2 pF compared to 200 pF). If we consider the parasitic capacitance of the interconnect microstrip line and effects due to fabrication process, the variation could be the same order as the value of the coupling capacitor itself. This leads to a wide pass band, a high insertion loss and large pass band ripple.

After adjusting the coupling capacitor value according to the testing result, the simulation gives similar filter response to our experiment (Fig. 6).

In the next step, more small interdigital capacitors with interconnecting wires will be tested. Accordingly, the layout will be modified in order to absorb the parasitic capacitance.

III. Conclusions

We have designed, fabricated and tested three-pole microstrip bandpass filters at high frequency (HF) range for the first time. The models for lumped elements fits well with our experimental data. The resonators of the filter give high Q values. Some modifications will be made to the matching capacitors to reduce the insertion loss and bandwidth of the filter.

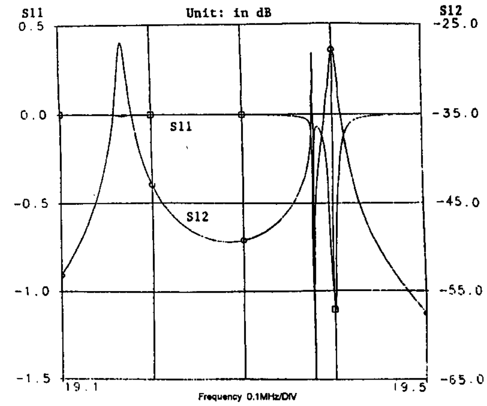

Fig. 6. Simulation result after adjusting coupling capacitors.

References

[1] M. J. Lancaster, F. Huang, A. Porch, B. Avenhaus, J. Hong, and D. Hung, "Miniature Superconducting Filters," *IEEE Trans. Microwave Theory Tech.*, vol. 44, no. 7, pp. 1339-46, July 1996.

[2] G.-C. Liang, D. Zhang, C.-F. Shih, M. E. Johansson, and R. S. Withers, "High-power high-temperature superconducting microstrip filter for cellular base-station applications," *IEEE Trans. Appl. Supercondut.*, vol. 5, no. 2, pp. 2652-55, June 1995.

[3] R. R. Mansour and Andre Zybura, "Superconducting millimeter-wave E-plane Filters," *IEEE Trans. Microwave Theory Tech.*, vol. 39, no. 9, pp. 1488-92, Sept. 1991.

[4] S. H. Talisa, M. A. janocko, D. L. Meier, C. Moskowitz, R. L. Grassel, J. Talvacchio, P. LePage, G. Hira, D. C. Buck, S. J. Pieseski, J. C. Brown, and G. R. Wagner, "A high temperature superconducting four-channel filterbank," *Microwave Journal*, pp. 106-112, July 1996.

[5] K. Kang, S. Y. Lee, and S. K. Han, "Microwave multipole lowpass and bandpass filters fabricated by high-Tc superconducting thin films," *IEEE Trans. Appl. Supercondut.*, vol. 5, no. 2, pp. 2671-4, June 1995.

[6] B.Oh, H. T. Choi, S. H. Moon, P. H. Hur, and M. Kim, "A compact two-pole X-band high-temperature superconducting microstrip filter," *IEEE Trans. Appl. Supercondut.*, vol. 5, no. 2, pp. 2667-70, June 1995.

[7] Gary D. Alley, "Interdigital Capacitors and Their Application to Lumped-Element Microwave Integrated Circuits," *IEEE Trans. MTT.*, vol. MTT-18, no. 12, pp. 1028-1033, Dec 1970.

[8] N. Newman and W. G. Lyons, "High-temperature superconducting Microwave devices: fundamental issues in materials, physics, and engineering," *J. Superconduct.* vol. 6, no. 3, pp. 119-58, 1993.

[9] E. Belohoubek, D. Kalokitis, A. Fathy, E. Denlinger, A. Pique, X. D. Wu, S. M. Green, and T. Venkatesan, "High temperature superconducting components for microwave systems," *Applied Superconduct.*, vol. 1, no. 10-12, pp. 1555-73, 1993.

[10] F. S. Thomson, R. R. Mansour, S. Ye, and W. Jolley, "Current density and power handling of high-temperature superconductive thin film resonators and filters," *IEEE Trans. Appl. Supercondut.*, vol. 8, no. 2, pp. 85-93, June 1998.

[11] Frederick W. Grover, *Inductance Calculations Working Formulas and Tables* D.Van Nostrand Company, Inc. New York 1946.

[12] Hewlett Packard *EESof IV User's Guide.*